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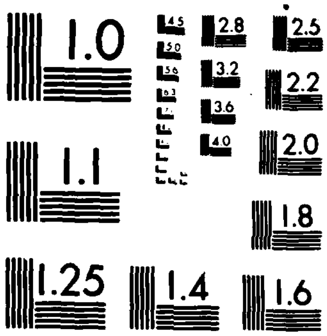

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AN INTEGRATING DOSIMETER FOR PULSED RADIATION

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A Pulsed Radiation Dosimetry System designed to measure radiation produced by particle accelerators is described. The problems associated with total-dose measurement of irregular shaped pulses of ionizing radiation have been simplified. The system responds to extremely narrow pulses of charged particles or X-rays using a pin diode as the detector. Direct readout of dose in rads (Si) is displayed on a 3-1/2 digit digital panel meter. The system will operate in either the multiple-pulse or single-pulse mode. The multiple-pulse mode would be useful in monitoring or tuning a linear

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accelerator. In the single-pulse mode the system will automatically display total dose of a transient event in real time and hold that measurement indefinitely or until the next measurement is made. The system features an automatic reset in either mode.

Preface

The author wishes to acknowledge Lester Lowe for his enthusiastic support of the project and Walter Shedd for his patience during numerous discussions.

Contents

Illustrations

An Integrating Dosimeter for Pulsed Radiation

1. INTRODUCTION

To simulate man-made and natural ionizing radiation, research and test facilities make use of Linear accelerators (LINACS) and flash X-ray machines (FXRS). The radiation produced by these accelerators is used for radiation effects testing and evaluation of materials, components, and systems. Over the years, one of the problems facing the experimentor has been the ability to measure easily and accurately the quantity of radiation absorbed. Various techniques exist to establish the total-dose delivered by a particle accelerator to a sample or device under test. Frequently used methods such as thermoluminescent dosimeters, colorimeters, and semiconductor diodes are suitable depending on the particular applications. However, when using TLD's, a costly readout system is necessary for readout of the dosimeters. Also, the dosimeters must be changed for each radiation pulse causing delay in the operation of the accelerator and to the experimentor. Colorimeters, being active dosimeters, eliminate the time involved for readout but the results must be extropolated which lead to errors in the measurement. The use of semiconductor diodes for radiation measurement also leads to error because accelerators characteristically have irregular shaped pulses. This means the output of the diode must be photographed with a high speed oscilloscope and camera system for each radiation pulse. The photos must then be interpreted

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individually causing delays and errors in the results. The system described here greatly simplified the task by displaying directly, in rads (Si), the total-dose delivered to a calibrated pin diode. Results are obtained instantly without guessing at pulse width or amplitude. The need to photograph and interpret each pulse is eliminated, thereby saving time and expense. The need to enter the cell area to change TLD's or other passive monitors for each shot is significantly reduced.

The dynamic range of the system is 4×10^9 rads/sec to 2×10^5 rads/sec with a pulse width response of 5 μs to 20 ns. With these pulse parameters a maximum dose of 2×10^4 rads to a minimum of 1 rad is achieved. Saturation of the pin diode and resolution of the meter set the high and low dose range limits respectively. Readout of a single event is displayed until the next event occurs. Each succeeding radiation pulse will automatically zero the system and be displayed. Repetition rates up to 120 pps are possible when used in the multiple pulse mode.

2. CIRCUIT DESCRIPTION

Description of the circuit is divided into six sections. A block diagram and circuit schematic are shown in Figures 1 and 2.

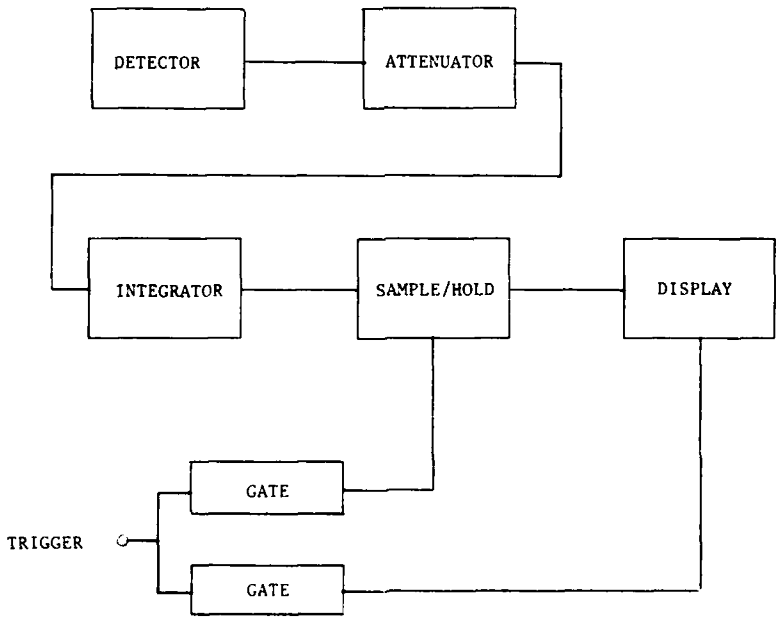

Figure 1. Block Diagram

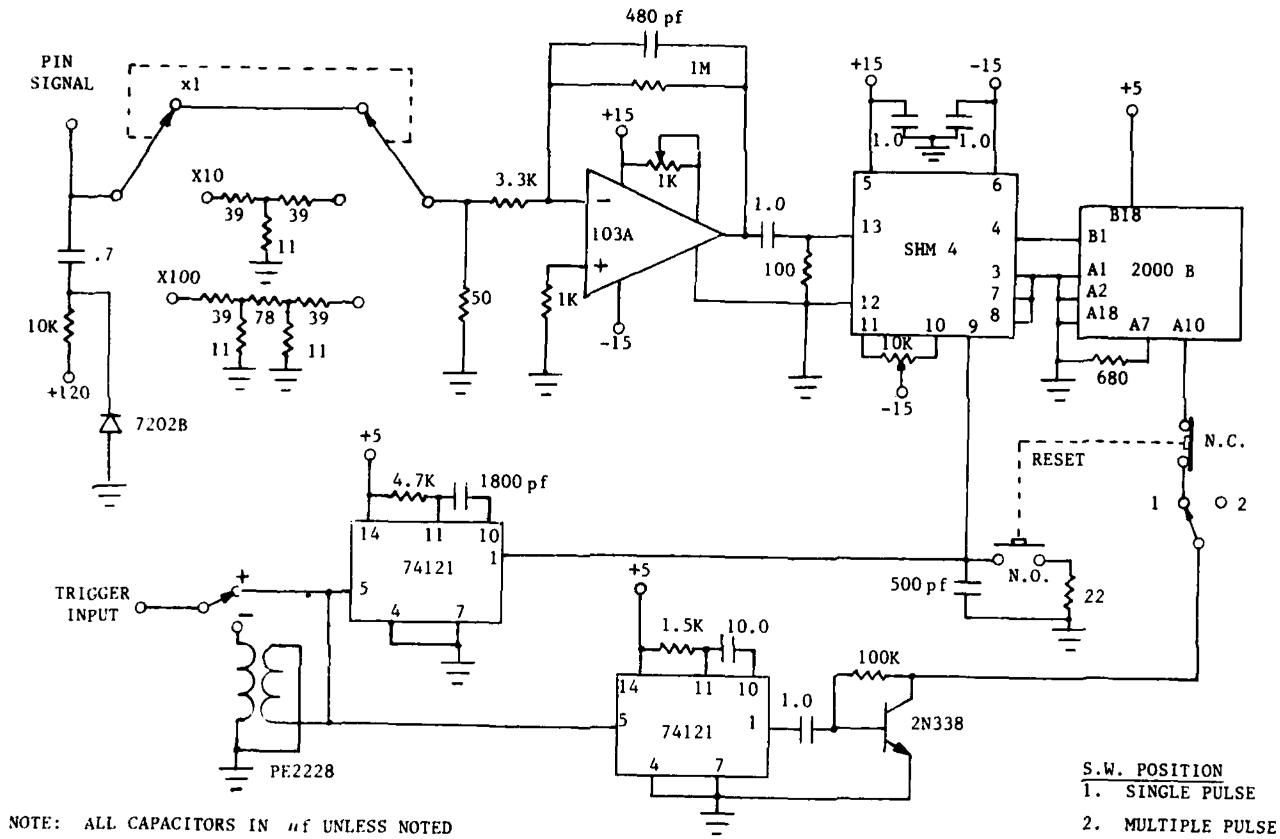

Figure 2. Circuit Diagram

2.1 Detector

Pin diodes behave much like ionization chambers when used as radiation detectors. The output response of the pin diode detector is proportional to the energy that is deposited in the depletion region. The current which is generated in the depletion region by incident radiation is measured by sampling the voltage across a load resistor. By convention, calibration factors for pin diodes are expressed in terms of rads $\cdot$ $sec^{-1} \cdot V^{-1}$, therefore, knowing pulse shape, total dose may be obtained.

A Unitrode Pin Diode series UM7200 was used as the radiation detector. A female BNC cable connector such as FXR No. 68150, was modified to mount the pin and offer protection during use. The diode mount was constructed so that it will closely approximate the surface dose rate for measurement of electrons and X-rays. With a wall thickness of 0.25 mm for the mount and half the thickness of the diode, 1.14 mm, a total thickness of 1.39 mm is achieved. This provides the minimum amount of material practical for the pin diode package and is a reasonable approximation of surface dose.

The composition of the diode lends itself nicely as a radiation detector. Since the diode is silicon and its mount aluminum, dose may be expressed in rads (Si). In the field of radiation testing and evaluation of components and systems, a direct measurement of dose in rads (Si) is convenient since silicon is used extensively today in the manufacture of semiconductors. The small size of the diode is useful in locating it near a sample under test thereby minimizing geometry corrections. In particle beam uniformity applications, resolution in the order of 3.5 mm may be obtained.

Calibration of the mounted pin diode against a Controls for Radiation Inc. Thermoluminescent Dosimetry System using CaF_2(Mn) teflon discs 5.5 mils thick, resulted in a calibration factor of 6.7×10^7 rads (Si) $\cdot$ $sec^{-1} \cdot V^{-1}$. The calibration factor was obtained using 10 MeV electrons from a linear accelerator and placing the TLDs in an aluminum package equivalent to the thickness of the pin diode and its mounting connector.

2.2 Attenuator

Maximum output signal of the pin diode is in the order of 50-60 V, therefore, attenuation is necessary to prevent overloading the input of the integrator.

Signal attenuation is provided by a manually operated range switch which provides three ranges of attenuation. In position 1, the full output of the pin diode is applied to the integrator input when the radiation signal is in the range of 1 to 199 rads. In position 2, the pin diode signal is attenuated by 20 dB using a single T section resistive attenuator. The useful range of the system in position 2 is

10 to 1999 rads and requires multiplying the display by 10. In position 3, a dual T section resistive attenuator is used to reduce the pin signal 40 dB which results in a radiation signal equivalent to a range of 100 to 19999 rads. This requires multiplying the display by 100. An overflow display on the digital panel meter indicates when range changing is necessary.

2.3 Integrator

One of the techniques used to measure radiation pulse total-dose is to record the pulse profile using a pin diode or other radiation sensitive device with an oscilloscope and camera. The recorded pulse width and amplitude of the waveform is then measured and applied to a conversion factor to obtain dose rate or total-dose. However, because of the irregularity in the pulse shape of particle accelerator beams, much difficulty is encountered in interpreting the results.

The Pulsed Radiation Dosimetry System overcomes this problem by electronically integrating the output of a pin diode. The integrator section of the system makes use of a Datel model AM-103 Wide-band Operational Amplifier. The op-amp is used as a conventional inverting analog pulse integrator with capacitive feedback and dc stabilization. The integrator output voltage is proportional to the time integral of the pin diode signal times a constant, which may be given by

$$E_o = - 1/RC \int E_{in} \, dt .$$

The circuit values are determined by the pin diode calibration factor, the time constant of the integrator, and the voltage range of the digital display.

The following calculations will provide typical circuit values.

<u>For the Integrator</u>

$$E_o = - 1/RC \int e_{in} \, dt$$

where

E_o = integrator output voltage, V

R = value of input resistor, Ω

C = Value of Feedback Capacitor, F

E_{in} = integrator input voltage, V

dt = radiation pulse width, sec

For the Pin Diode

Calibration factor = 6.7×10^{7} rads · sec^{-1} · V^{-1}

where

$$sec = dt$$

$$V = E_{in}$$

For the Digital Display (DPM)

Full scale input range = 1.999 V = E_o and

E_o = rads × multiplier

therefore

$$RC = E_{in}\, dt/E_o$$

$$RC = 60 \times 0.01 \times 5 \times 10^{-6}/199.9 \times 100$$

$$RC = 1.5 \times 10^{-6} \text{ sec}$$

where

$$E_{in} = 60\ V \times 0.1 \text{ (max attenuation)}$$

$$dt = \text{max pulse width}$$

$$E_o = 199.9 \times 100 \text{ (multiplier)}.$$

Thus any value of R and C that yields 1.5×10^{-6} may be used, however, current and loading limitations placed on R restricts its values between 2K Ω and 5K Ω.

If $R = 3.3K\ \Omega$

then $C = 1.5 \times 10^{-6}/3300$

and $C = 450$ F.

These turn out to be reasonable values since making C too large would cause a nonlinearity in the ramp voltage. Also, a resistor equal in value to R must be placed at the noninverting input to ground for minimum error resulting from bias current. A potentiometer is used to adjust the offset voltage to zero with no applied signal.

2.4 Sample-Hold

In order to be able to read the integrated output of the pin diode it is necessary for the integrator to hold its output value for a time of a few seconds. This would be enough time for a visual observation by the user. Unfortunately, the decay time is much too rapid to obtain a reading without further processing. Decay time is approximately 3 mV/μsec for the values given in the integrator.

A Datel model SHM-4 module is used to sample the output of the integrator and hold this value long enough for the digital panel meter to respond. This requires a decay time several orders of magnitude longer than the integrator. The SHM-4 output droop in the hold mode is rated at less than 20 V/msec. The circuit is used in the noninverting mode with no gain.

Signal output from the integrator is applied to the sample-hold input. Simultaneously, a gate pulse is applied to the digital input to sample the input pulse (see Figure 3). With no gate pulse present the sample-hold output will hold the value sampled at 6 μsec for a time determined by the output droop. The system is automatically reset whether in the single or multiple pulse mode by the action of the gate pulse. Since the integrator output has returned to zero volts before the next input pulse arrives, the gate pulse starts sampling at the integrator zero level. A manual reset switch is available to check the zero level during multiple pulse operation. With no signal at the input or the input grounded, sample offset and hold offset voltage is adjusted to zero volts.

2.5 Gate and Driver

Timing for the Pulsed Radiation Dosimetry System is provided by two monostable multivibrators both of which are triggered by a positive or negative going transition. One of the multivibrators MV-1 gates the sample-hold module as discussed earlier. The second multivibrator MV-2 provides a gate pulse for the driver transistor which in turn operates the read and hold function on the digital panel meter. Pulse width for both multivibrators is determined by the relationship

$$t_w = RC\ n^2$$

where

R = value of external resistor in Ω

C = value of external capacitor in F.

A pulse width of 6 μsec with an amplitude of +4 V is used as the gate for the sample command since the widest radiation pulse to be detected is 5 μsec. This allows sampling of the integrator output at its peak value. The width of the gate pulse for MV-2 is set at 10 msec with an amplitude of -3.5 V. A dc level of +4 V is needed for the hold command.

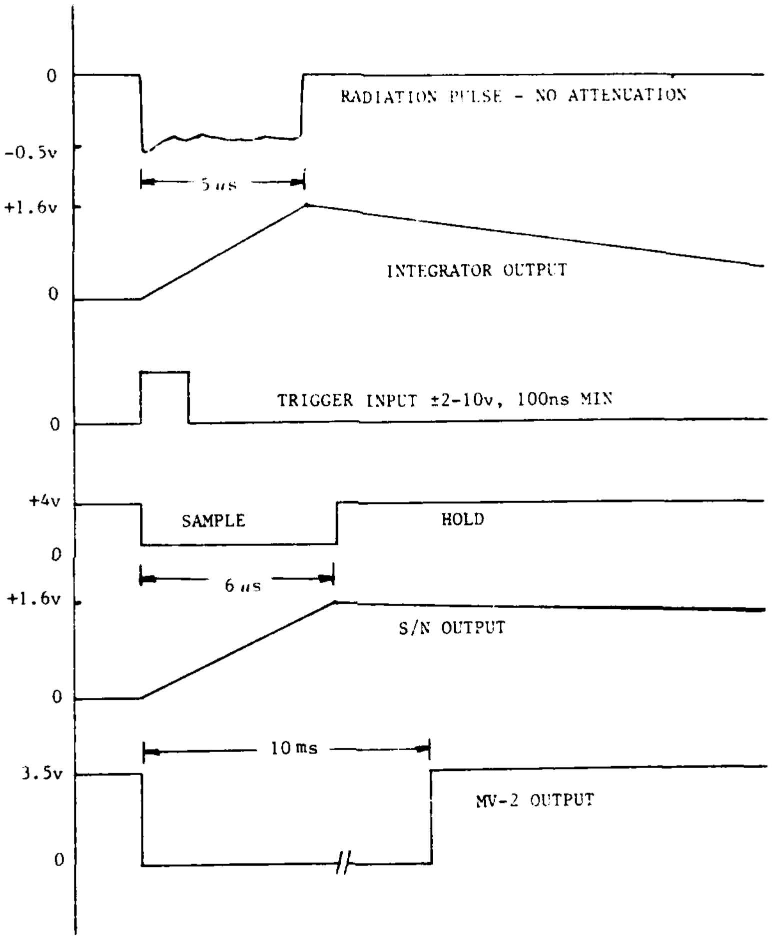

Figure 3. Circuit Timing

2.6 Readout

A Datel model DM-2000 series Digital Panel Meter with 3-1/2 digit resolution is used for a readout in the system. The meter has a full scale input range of 1.999 V and a resolution of 1 mV.

When the system is being used in its single pulse mode the meter will automatically read and hold its last display. This is accomplished by the driver Q1 momentarily removing pin A-10 of the meter from ground during a radiation pulse. In the multiple pulse mode, the meter will sample and display at a rate of 120 samples per second.

An overflow indication will occur when the input voltage to the meter exceeds full scale. All the digits are then blanked and the characters "OF" are displayed.

The meter also provides decimal point selection by grounding the appropriate pin on the connector. In this application pin A-7 is grounded to place the decimal before the least significant digit. With the decimal point in this position the meter will read directly in rads times the attenuator setting.

3. CONCLUSION

A convenient apparatus for radiation monitoring and measurement of charged particles and X-rays has been developed. The apparatus provides improved pulsed radiation dosimetry by combining features, such as: wide dynamic range, direct readout of dose in real time and two modes of operation. Extensive cross calibrations with CaF_2 (Mn) thermoluminescent dosimeters on both a 10 MeV Linear Accelerator and a 2 MeV Flash X-Ray Accelerator have proven the system to be a dependable instrument for the measurement of pulsed ionizing radiation.

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